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(54) SWITCH FOR RAPID CYCLE HIGH POWER APPLICATIONS

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Granted to Briggs & Stratton Corporation, Wauwatosa, Wisconsin, U.S.A.

(21) APPLICATION No. 100,277
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No. OF CLAIMS 2

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This invention relates to magnetically actuated reed switches and more particularly to a reed switch that is especially well suited for use in a circuit that carries substantially high power and must be opened and closed at recurrent intervals of short but variable duration.

This application is a division of my copending application Serial No. 074,063, filed February 5, 1970.

Magnetically actuated reed switches have been available for many years, and have long been recognized as potentially useful in many applications. In practice, however, such switches have heretofore had limited utility because of their inability to operate satisfactorily in high volt-ampere circuits and to respond accurately to short, rapidly recurring cycles of build-up and decay of a magnetic actuating field. For example, one such switch, recently placed on the market and considered to represent an advanced state of the art, was rated for 240 operations per minute and to break 3 amps. at 125 volts, a.c., and 2 amps. at 250 volts, a.c.

To some extent this recent switch sacrificed high cycle speed to gain power handling capability, since previously marketed reed switches intended for lower power were capable of cycle speeds on the order of 60 operations per second.

Operating frequencies many times the 240 opm of this recent switch are needed for numerous applications in which reed switches are potentially useful (e.g., computers); and power ratings substantially higher than 500 volt-amperes at break are likewise essential in many cases (e.g., machine tool controls), and are desirable in all cases where they can be obtained without sacrificing other important characteristics.

For broadest utility, a reed switch should have a

long service life as well as a high cycle speed and a high power rating. The above mentioned recently marketed reed switch had an advertised life expectancy of only 500,000 operations when breaking 3 amps. at 120 volts a.c. Under conditions of rapid cycling this would represent an extremely short service life, e.g. less than 40 hours at 240 opm.

The reed switch disclosed and claimed in Canadian Patent No. 824,230, issued September 30, 1969, to. J. D. Santi, has been found to provide consistently accurate timing of make and break at frequencies of more than 200 operations per second, as well as at all lower cycle speeds. But while the invention of that patent achieved very high cycle speeds, it did not solve the long standing problem of providing a reed switch with both high cycle speed and the capacity for handling large amounts of power.

The present invention has as its general object to achieve a substantial advance over the state of the reed switch art represented by Canadian Patent No. 824,230, and, specifically, to provide a reed switch that not only compares favorably in cycle speed with the switch of said patent, but in addition, has the ability to break circuits carrying on the order of 1500 volt-amperes, and has a service life expectancy on the order of hundreds of millions of operations at its rated power.

The useful life of a switch depends upon the current that it is required to interrupt, particularly if it must always open when current is flowing in the same direction, as in a d.c. circuit.

It is well known that even when a switch opens without the occurence of a spark or arc between its contacts, some transfer of material between its contacts nevertheless takes place at each opening. This arcless transfer, which is known in the art

as "low voltage phenomenon", always takes place from the positive contact to the negative one. It occurs with tungsten contacts operating in air or in a deep vacuum, as well as with contacts of the other metals, operating in any environment. When a switch is used in d.c. service, arcless transfer of material always takes place in the same direction, and the transfers occurring in successive openings are cumulative so that the service life of the switch depends upon the volume of its contact material and the current to be interrupted. The same switch, operating in comparable a.c. service, will normally have a substantially longer useful life because the switch does not always open at the peak current in the cycle and, further, because each contact is the positive one in about 50% of the openings of the switch so that material transferred during any one opening will be transferred back to its original site in a subsequent opening.

With the foregoing in mind, it is an object of this invention to provide a switch that has contacts which overcome to a very substantial extent the problem posed by the low voltage phenomenon just described, so that the switch of this invention has an extraordinarily long useful life even in high current d.c. applications.

More specifically, it is an object of this invention to provide a switch for relatively high power applications, having contacts which permit an incipient arcing to take place at each opening of the switch, and wherein the incipient arcing thus permitted offsets to a substantial extent the transfer of material from the positive to the negative contact that also occurs at each switch opening, to thus afford the switch of this invention a long useful life, even in d.c. service.

With these observations and objects in mind, the

manner in which the invention achieves its purpose will be appreciated from the following description and the accompanying drawings. This disclosure is intended merely to exemplify the invention. The invention is not limited to the particular structure disclosed, and changes can be made therein which lie within the scope of the appended claims without departing from the invention.

The drawings illustrate one complete example of the physical embodiment of the invention constructed according to the best mode so far devised for the practical application of the principles thereof, and in which:

Figure 1 is a view in side elevation of a reed switch embodying the principles of this invention with a portion of its envelope shown broken away, the switch being illustrated in its normal open condition;

Figure 2 is a view similar to Figure 1 but showing the switch in its closed condition;

Figure 3 is a disassembled perspective view of the components of the switch of this invention that are inside its envelope; and

Figure 4 is a view in front elevation of the reed assembly that includes the contactor.

Referring now to the accompanying drawings the numeral 5 designates generally a reed switch embodying the principles of this invention, comprising a pair of elongated, resiliently flexible, magnetically permeable reeds 6 and 6' enclosed in an elongated hermetically sealed envelope 7 of glass or the like. The envelope is evacuated to a deep vacuum. Extending through the sealed ends of the envelope are a pair of elongated terminal members 8 and 8', one for each of the reeds 6 and 6'. Each of the terminal members supports its reed at its inner end and has its outer end

portion exposed to provide one of the terminals 9, 9' of the switch.

The reeds 6 and 6' extend axially inwardly from their respective terminal members 8 and 8', and their free tip portions are disposed in lengthwise overlapping relationship in the medial portion of the envelope, normally spaced apart laterally by a predetermined distance to define a gap 10. Under the influence of a magnetic field that threads the reeds and the gap 10, the reeds are flexed to bring their overlapping tip portions into contact with one another.

Also secured to the inner end of each terminal member 8, 8' is an elongated, relatively stiff post or rebound stop which extends lengthwise along the reed at the side of the latter that is remote from the other reed, the post for the reed 6 being designated 11 and the post for the reed 6' being designated 11'. Since each reed is formed from flat strip material, it can be said to have a rear surface that faces its post and a front surface that faces the other reed.

Each reed normally engages its post under flexing bias so as to have a rearward preload against the post in accordance with the teachings of the above mentioned Canadian Patent No. 824,230, to which reference may be made for an explanation of the advantages of this arrangement and the manner in which it affords extremely high cycle speed in a reed switch.

In accordance with the present invention the reed 6 carries a contactor 12 which normally engages the rear surface of said reed 6 under forward flexing bias and which has a contact portion 13 that projects forwardly across the tip of the reed 6 to be normally spaced from the reed 6' by a distance somewhat smaller than that across the gap 10 between the tip portions of the reeds themselves. As explained more fully hereinafter, the contactor has

several functions, one of which is to prevent failure of the switch due to sticking of its contacts under high current surges.

Turning now to a more detailed consideration of the switch structure, the envelope 7 is preferably made of a length of glass tubing that has its opposite end portions respectively drawn down around the terminal members 8 and 8' and fused to them to hold the terminal members 8 and 8' in rigidly fixed substantially coaxial relationship with one another and to provide hermetic seals around them.

As shown, the terminal members have their inner ends spaced apart axially by a substantial distance, and each has a post 11, 11' welded to its inner end; but it will be apparent that each terminal member could comprise an integral axially outward extension of its post. The length of each post is such that its tip is near the tip of its reed. As explained in Canadian Patent No. 824, 230, the post can be of either magnetic or nonmagnetic material, but it should in any case be substantially stiffer than the reed.

In accordance with the present invention, each of the reeds 6 and 6' has a substantially flat anchor portion 15 adjacent its captive end, a substantially flat armature portion 16 that comprises its free end, and a medial neck portion 17 that has a smaller cross-sectional area than the anchor and armature portions and is bent at obtuse angles to them. The neck portion is of course integral with the anchor and armature portions and connects them. The anchor portion 15 of each reed flatwise overlies its adjacent post near the captive end thereof and can be secured to the post as by welding. The neck portion 17 extends obliquely forwardly, away from the post and toward the reed tip. The armature portion 16 is normally inclined toward the post to have its

tip engaging the post under rearward flexing bias.

It is intended that most of the flexing of the reed of this invention shall take place in its neck portion 17, and to this end the neck portion has a reduced cross-section area. Preferably the smaller cross-section area of the neck portion is obtained by reducing only its thickness, as shown, to insure that the reed has a relatively flat spring rate, that is, to have the flexing stress forces in the reed increase relatively gradually with forward displacement of the reed tip toward the other reed.

The neck portion 17 of each reed extends obliquely to its armature portion 16 in order to minimize contact bounce when the reed tips engage one another. The tendency of the armature portion to rebound is manifested in a vibration of the armature portion transversely to its flat faces. But because the neck portion extends obliquely to the armature portion, such vibration has a substantial component lengthwise of the neck portion. Furthermore, the armature portion is relatively short. For these reasons, the frequency of reed vibration due to any contact rebound tends to be high, and the amplitude of such vibration tends to be small. Such high frequency vibration dissipates energy rapidly, and because of its low amplitude there is little energy to dissipate. Therefore such "make bounce" as may occur in the reed switch of this invention poses no practical problem, even at the fast closure rates that are a concomitant of high cycle speed.

It will be understood, of course, that the provision of a post or rebound stop for each reed, against which the reed is preloaded, further contributes to the minimization of "make bounce", permits the gap 10 to be a small one, and makes possible the use of reeds having a low spring rate in a switch intended for successive operations at short intervals.

Since the reeds engage one another with substantial force upon closure of the switch, the front surfaces of their tip portions have tungsten coatings 18. Because of their hardness, these tungsten coatings resist mechanical wear and they prevent the reed tips from sticking together as a result of cold welding or mechanical friction; and because of the low current flowing between the contacts 18 as they engage and separate, due to the functioning of the contactor 12 as explained hereinafter, those contacts have no tendency to be welded together especially in view of the high melting temperature of tungsten. Because of the oxygen-free environment of the tungsten contacts 18 in the switch of this invention, they do not oxidize and therefore their contact resistance remains low during the life of the switch, instead of increasing like the resistance of contacts operating in air.

On the reed 6' there must also be a tungsten coating 23 that provides a contact engageable by the contact portion 13 of the auxiliary contactor 12, for reasons explained hereinafter. This contact 23 can of course comprise a continuation of the tungsten coated area that forms the contact 18 at the tip of that reed. (See Figures 3 and 4.)

While the high cycle speed of the switch of this invention is in large measure due to the preload of its reeds 6 and 6' against the posts 11 and 11', its ability to control high volt-ampere circuits is mainly attributable to the contactor 12 that is carried by the reed 6, although as will appear in the course of the description, the contactor also performs certain other important functions.

The contactor should be light in weight so that it does not greatly increase the mass of the reed 6 by which it is carried, and it must be substantially resilient. These requirements

are nicely met by molybdenum wire, which also possesses other very important advantages that are discussed hereinafter.

The molybdenum wire contactor 12 is bent generally to an elongated U that has its legs 19 curved inwardly back upon themselves near their free end portions, around loops 20, to provide coplanar anchoring elements 21 that comprise the end portions of the length of wire. These anchoring elements flatwise overlie the front face of the armature portion 16 of the reed 6 and they are welded or otherwise bonded thereto. By reason of jog-like bends 22 in the legs 19 of the contactor, the anchoring elements 21 and loops 20 lie in a plane that is spaced forwardly from the plane of the remainder of the legs 19, and the portions of said legs that lie between the bends 22 and the bight portion 27 of the contactor define a spring arm which overlies the rear face of the armature portion 16 of the reed and which normally engages the armature portion under forward bias. At its bight portion 17 the legs 19 of the contactor are spaced apart a distance substantially less than the width of the reed, but they diverge substantially toward the neck portion 17 of the reed and are spaced laterally from the side edges thereof.

The bight portion of the contactor, which lies outwardly of the tip of the reed 6 and which comprises the contact 13 thereof, is bent at right angles to its spring arm portion to project forwardly across the tip of said reed and beyond the front surface thereof so that with the switch in its normally open position the distance between the contact 13 and the reed 6' is less than that between the reeds themselves.

As the reeds converge under the influence of a magnetic field, the contact 13 on the contactor 12 engages the contact 23 on the reed 6' before the contacts 18 on the reeds themselves

come into engagement. Because of the forward preload of the contactor against the reed 6, the force required to bring the reeds into contact with one another increases markedly when the contactor engages the reed 6'. In other words, once the contactor 12 engages the reed 6', the magnetic attraction force acting on each reed is yieldingly resisted by the flexing force of the reed itself combined with that of the contactor 12.

As pointed out hereinabove, when the reeds move toward one another under the influence of a magnetic field, they are accelerated rapidly, right from the beginning of their converging motion. Hence the reeds have substantial forward momentum at the instant the contactor engages the reed 6'. Furthermore, the magnetic force acting upon them at that instant is substantially large in relation to the flexing forces that they oppose to it. Since the contactor has forward preload, these inertia and magnetic forces combine to very nearly eliminate contact bounce between the contactor and the reed 6'. Such slight vibration as may occur immediately following impact of the contactor against the reed 6' will be of very high frequency and small amplitude, due to the rapidly building force with which the contactor is urged against that reed, and such vibration will therefore be very quickly dissipated.

After the contactor engages the reed 6', the armature portions of the two reeds continue to converge rapidly, but the net spring force resisting their convergence does not increase quite as rapidly as the magnetic force attracting them into engagement. For this reason, as well as for the reasons pointed out hereinabove, the armature portions of the reeds will have little tendency toward "make bounce" when they engage; but of course if they should rebound, the switch will nevertheless remain effectively

closed because the contactor will remain engaged against the reed 6' with a contact force substantially equal to the preload under which it normally engages the reed 6.

It will be noted that most of the flexing of the contactor takes place in its loop portions 20, which are located closely adjacent to the neck portion 17 of the reed. Hence the contact 13 of the contactor 12 and the armature portion 16 of the reed 6 tend to swing about a common center, with the result that the contact 13, once engaged with its cooperating contact 23, has substantially no wear producing movement across the surface thereof even though the armature portion of the reed 6 continues to swing.

When the switch of this invention is fully closed, the contacts on the two reeds, comprising the tungsten coatings 18, provide a second current path through the switch, cooperating with the contacts 13 and 23 on the contactor and the reed 6', respectively, to provide the switch of this invention with a relatively low net resistance whereby it is well suited for low voltage applications as well as for high power circuits.

While the contactor 12 performs very important functions in preventing "make bounce" and in maintaining low net resistance through the closed switch, its role during switch opening is perhaps even more important.

As pointed out above, the reeds in the switch of this invention have a very flat and relatively low spring rate so that they respond promptly and consistently to a rapidly building magnetic field. But sticking is always a problem with switch contacts that must open a high power circuit, even with high melting contacts operating in a deep vacuum; hence reeds of low stiffness could not, by themselves, exert sufficient contact separating force to interrupt a circuit carrying high power. In the switch of the

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(12) **Patent:** (11) **CA 886158**

(54) SWITCH FOR RAPID CYCLE HIGH POWER APPLICATIONS

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ABSTRACT:

CLAIMS: Show all claims

*** Note: Data on abstracts and claims is shown in the official language in which it was submitted.

(72) Inventors (Country):	**JOHN D. SANTI** (Not Available)
(73) Owners (Country):	**BRIGGS AND STRATTON CORPORATION** (Not Available)
(71) Applicants (Country):	
(74) Agent:	
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To some extent this recent switch sacrificed high cycle speed to gain power handling capability, since previously marketed reed switches intended for lower power were capable of cycle speeds on the order of 60 operations per second.

Operating frequencies many times the 240 opm of this recent switch are needed for numerous applications in which reed switches are potentially useful (e.g., computers); and power ratings substantially higher than 500 volt-amperes at break are likewise essential in many cases (e.g., machine tool controls), and are desirable in all cases where they can be obtained without sacrificing other important characteristics.

For broadest utility, a reed switch should have a

long service life as well as a high cycle speed and a high power rating. The above mentioned recently marketed reed switch had an advertised life expectancy of only 500,000 operations when breaking 3 amps. at 120 volts a.c. Under conditions of rapid cycling this would represent an extremely short service life, e.g. less than 40 hours at 240 opm.

The reed switch disclosed and claimed in Canadian Patent No. 824,230, issued September 30, 1969, to. J. D. Santi, has been found to provide consistently accurate timing of make and break at frequencies of more than 200 operations per second, as well as at all lower cycle speeds. But while the invention of that patent achieved very high cycle speeds, it did not solve the long standing problem of providing a reed switch with both high cycle speed and the capacity for handling large amounts of power.

The present invention has as its general object to achieve a substantial advance over the state of the reed switch art represented by Canadian Patent No. 824,230, and, specifically, to provide a reed switch that not only compares favorably in cycle speed with the switch of said patent, but in addition, has the ability to break circuits carrying on the order of 1500 volt-amperes, and has a service life expectancy on the order of hundreds of millions of operations at its rated power.

The useful life of a switch depends upon the current that it is required to interrupt, particularly if it must always open when current is flowing in the same direction, as in a d.c. circuit.

It is well known that even when a switch opens without the occurence of a spark or arc between its contacts, some transfer of material between its contacts nevertheless takes place at each opening. This arcless transfer, which is known in the art

as "low voltage phenomenon", always takes place from the positive contact to the negative one. It occurs with tungsten contacts operating in air or in a deep vacuum, as well as with contacts of the other metals, operating in any environment. When a switch is used in d.c. service, arcless transfer of material always takes place in the same direction, and the transfers occurring in successive openings are cumulative so that the service life of the switch depends upon the volume of its contact material and the current to be interrupted. The same switch, operating in comparable a.c. service, will normally have a substantially longer useful life because the switch does not always open at the peak current in the cycle and, further, because each contact is the positive one in about 50% of the openings of the switch so that material transferred during any one opening will be transferred back to its original site in a subsequent opening.

With the foregoing in mind, it is an object of this invention to provide a switch that has contacts which overcome to a very substantial extent the problem posed by the low voltage phenomenon just described, so that the switch of this invention has an extraordinarily long useful life even in high current d.c. applications.

More specifically, it is an object of this invention to provide a switch for relatively high power applications, having contacts which permit an incipient arcing to take place at each opening of the switch, and wherein the incipient arcing thus permitted offsets to a substantial extent the transfer of material from the positive to the negative contact that also occurs at each switch opening, to thus afford the switch of this invention a long useful life, even in d.c. service.

With these observations and objects in mind, the

manner in which the invention achieves its purpose will be appreciated from the following description and the accompanying drawings. This disclosure is intended merely to exemplify the invention. The invention is not limited to the particular structure disclosed, and changes can be made therein which lie within the scope of the appended claims without departing from the invention.

The drawings illustrate one complete example of the physical embodiment of the invention constructed according to the best mode so far devised for the practical application of the principles thereof, and in which:

Figure 1 is a view in side elevation of a reed switch embodying the principles of this invention with a portion of its envelope shown broken away, the switch being illustrated in its normal open condition;

Figure 2 is a view similar to Figure 1 but showing the switch in its closed condition;

Figure 3 is a disassembled perspective view of the components of the switch of this invention that are inside its envelope; and

Figure 4 is a view in front elevation of the reed assembly that includes the contactor.

Referring now to the accompanying drawings the numeral 5 designates generally a reed switch embodying the principles of this invention, comprising a pair of elongated, resiliently flexible, magnetically permeable reeds 6 and 6' enclosed in an elongated hermetically sealed envelope 7 of glass or the like. The envelope is evacuated to a deep vacuum. Extending through the sealed ends of the envelope are a pair of elongated terminal members 8 and 8', one for each of the reeds 6 and 6'. Each of the terminal members supports its reed at its inner end and has its outer end

portion exposed to provide one of the terminals 9, 9' of the switch.

The reeds 6 and 6' extend axially inwardly from their respective terminal members 8 and 8', and their free tip portions are disposed in lengthwise overlapping relationship in the medial portion of the envelope, normally spaced apart laterally by a predetermined distance to define a gap 10. Under the influence of a magnetic field that threads the reeds and the gap 10, the reeds are flexed to bring their overlapping tip portions into contact with one another.

Also secured to the inner end of each terminal member 8, 8' is an elongated, relatively stiff post or rebound stop which extends lengthwise along the reed at the side of the latter that is remote from the other reed, the post for the reed 6 being designated 11 and the post for the reed 6' being designated 11'. Since each reed is formed from flat strip material, it can be said to have a rear surface that faces its post and a front surface that faces the other reed.

Each reed normally engages its post under flexing bias so as to have a rearward preload against the post in accordance with the teachings of the above mentioned Canadian Patent No. 824,230, to which reference may be made for an explanation of the advantages of this arrangement and the manner in which it affords extremely high cycle speed in a reed switch.

In accordance with the present invention the reed 6 carries a contactor 12 which normally engages the rear surface of said reed 6 under forward flexing bias and which has a contact portion 13 that projects forwardly across the tip of the reed 6 to be normally spaced from the reed 6' by a distance somewhat smaller than that across the gap 10 between the tip portions of the reeds themselves. As explained more fully hereinafter, the contactor has

several functions, one of which is to prevent failure of the switch due to sticking of its contacts under high current surges.

Turning now to a more detailed consideration of the switch structure, the envelope 7 is preferably made of a length of glass tubing that has its opposite end portions respectively drawn down around the terminal members 8 and 8' and fused to them to hold the terminal members 8 and 8' in rigidly fixed substantially coaxial relationship with one another and to provide hermetic seals around them.

As shown, the terminal members have their inner ends spaced apart axially by a substantial distance, and each has a post 11, 11' welded to its inner end; but it will be apparent that each terminal member could comprise an integral axially outward extension of its post. The length of each post is such that its tip is near the tip of its reed. As explained in Canadian Patent No. 824, 230, the post can be of either magnetic or nonmagnetic material, but it should in any case be substantially stiffer than the reed.

In accordance with the present invention, each of the reeds 6 and 6' has a substantially flat anchor portion 15 adjacent its captive end, a substantially flat armature portion 16 that comprises its free end, and a medial neck portion 17 that has a smaller cross-sectional area than the anchor and armature portions and is bent at obtuse angles to them. The neck portion is of course integral with the anchor and armature portions and connects them. The anchor portion 15 of each reed flatwise overlies its adjacent post near the captive end thereof and can be secured to the post as by welding. The neck portion 17 extends obliquely forwardly, away from the post and toward the reed tip. The armature portion 16 is normally inclined toward the post to have its

tip engaging the post under rearward flexing bias.

It is intended that most of the flexing of the reed of this invention shall take place in its neck portion 17, and to this end the neck portion has a reduced cross-section area. Preferably the smaller cross-section area of the neck portion is obtained by reducing only its thickness, as shown, to insure that the reed has a relatively flat spring rate, that is, to have the flexing stress forces in the reed increase relatively gradually with forward displacement of the reed tip toward the other reed.

The neck portion 17 of each reed extends obliquely to its armature portion 16 in order to minimize contact bounce when the reed tips engage one another. The tendency of the armature portion to rebound is manifested in a vibration of the armature portion transversely to its flat faces. But because the neck portion extends obliquely to the armature portion, such vibration has a substantial component lengthwise of the neck portion. Furthermore, the armature portion is relatively short. For these reasons, the frequency of reed vibration due to any contact rebound tends to be high, and the amplitude of such vibration tends to be small. Such high frequency vibration dissipates energy rapidly, and because of its low amplitude there is little energy to dissipate. Therefore such "make bounce" as may occur in the reed switch of this invention poses no practical problem, even at the fast closure rates that are a concomitant of high cycle speed.

It will be understood, of course, that the provision of a post or rebound stop for each reed, against which the reed is preloaded, further contributes to the minimization of "make bounce", permits the gap 10 to be a small one, and makes possible the use of reeds having a low spring rate in a switch intended for successive operations at short intervals.

Since the reeds engage one another with substantial force upon closure of the switch, the front surfaces of their tip portions have tungsten coatings 18. Because of their hardness, these tungsten coatings resist mechanical wear and they prevent the reed tips from sticking together as a result of cold welding or mechanical friction; and because of the low current flowing between the contacts 18 as they engage and separate, due to the functioning of the contactor 12 as explained hereinafter, those contacts have no tendency to be welded together especially in view of the high melting temperature of tungsten. Because of the oxygen-free environment of the tungsten contacts 18 in the switch of this invention, they do not oxidize and therefore their contact resistance remains low during the life of the switch, instead of increasing like the resistance of contacts operating in air.

On the reed 6' there must also be a tungsten coating 23 that provides a contact engageable by the contact portion 13 of the auxiliary contactor 12, for reasons explained hereinafter. This contact 23 can of course comprise a continuation of the tungsten coated area that forms the contact 18 at the tip of that reed. (See Figures 3 and 4.)

While the high cycle speed of the switch of this invention is in large measure due to the preload of its reeds 6 and 6' against the posts 11 and 11', its ability to control high volt-ampere circuits is mainly attributable to the contactor 12 that is carried by the reed 6, although as will appear in the course of the description, the contactor also performs certain other important functions.

The contactor should be light in weight so that it does not greatly increase the mass of the reed 6 by which it is carried, and it must be substantially resilient. These requirements

are nicely met by molybdenum wire, which also possesses other very important advantages that are discussed hereinafter.

The molybdenum wire contactor 12 is bent generally to an elongated U that has its legs 19 curved inwardly back upon themselves near their free end portions, around loops 20, to provide coplanar anchoring elements 21 that comprise the end portions of the length of wire. These anchoring elements flatwise overlie the front face of the armature portion 16 of the reed 6 and they are welded or otherwise bonded thereto. By reason of jog-like bends 22 in the legs 19 of the contactor, the anchoring elements 21 and loops 20 lie in a plane that is spaced forwardly from the plane of the remainder of the legs 19, and the portions of said legs that lie between the bends 22 and the bight portion 27 of the contactor define a spring arm which overlies the rear face of the armature portion 16 of the reed and which normally engages the armature portion under forward bias. At its bight portion 17 the legs 19 of the contactor are spaced apart a distance substantially less than the width of the reed, but they diverge substantially toward the neck portion 17 of the reed and are spaced laterally from the side edges thereof.

The bight portion of the contactor, which lies outwardly of the tip of the reed 6 and which comprises the contact 13 thereof, is bent at right angles to its spring arm portion to project forwardly across the tip of said reed and beyond the front surface thereof so that with the switch in its normally open position the distance between the contact 13 and the reed 6' is less than that between the reeds themselves.

As the reeds converge under the influence of a magnetic field, the contact 13 on the contactor 12 engages the contact 23 on the reed 6' before the contacts 18 on the reeds themselves

come into engagement. Because of the forward preload of the contactor against the reed 6, the force required to bring the reeds into contact with one another increases markedly when the contactor engages the reed 6'. In other words, once the contactor 12 engages the reed 6', the magnetic attraction force acting on each reed is yieldingly resisted by the flexing force of the reed itself combined with that of the contactor 12.

As pointed out hereinabove, when the reeds move toward one another under the influence of a magnetic field, they are accelerated rapidly, right from the beginning of their converging motion. Hence the reeds have substantial forward momentum at the instant the contactor engages the reed 6'. Furthermore, the magnetic force acting upon them at that instant is substantially large in relation to the flexing forces that they oppose to it. Since the contactor has forward preload, these inertia and magnetic forces combine to very nearly eliminate contact bounce between the contactor and the reed 6'. Such slight vibration as may occur immediately following impact of the contactor against the reed 6' will be of very high frequency and small amplitude, due to the rapidly building force with which the contactor is urged against that reed, and such vibration will therefore be very quickly dissipated.

After the contactor engages the reed 6', the armature portions of the two reeds continue to converge rapidly, but the net spring force resisting their convergence does not increase quite as rapidly as the magnetic force attracting them into engagement. For this reason, as well as for the reasons pointed out hereinabove, the armature portions of the reeds will have little tendency toward "make bounce" when they engage; but of course if they should rebound, the switch will nevertheless remain effectively

closed because the contactor will remain engaged against the reed 6' with a contact force substantially equal to the preload under which it normally engages the reed 6.

It will be noted that most of the flexing of the contactor takes place in its loop portions 20, which are located closely adjacent to the neck portion 17 of the reed. Hence the contact 13 of the contactor 12 and the armature portion 16 of the reed 6 tend to swing about a common center, with the result that the contact 13, once engaged with its cooperating contact 23, has substantially no wear producing movement across the surface thereof even though the armature portion of the reed 6 continues to swing.

When the switch of this invention is fully closed, the contacts on the two reeds, comprising the tungsten coatings 18, provide a second current path through the switch, cooperating with the contacts 13 and 23 on the contactor and the reed 6', respectively, to provide the switch of this invention with a relatively low net resistance whereby it is well suited for low voltage applications as well as for high power circuits.

While the contactor 12 performs very important functions in preventing "make bounce" and in maintaining low net resistance through the closed switch, its role during switch opening is perhaps even more important.

As pointed out above, the reeds in the switch of this invention have a very flat and relatively low spring rate so that they respond promptly and consistently to a rapidly building magnetic field. But sticking is always a problem with switch contacts that must open a high power circuit, even with high melting contacts operating in a deep vacuum; hence reeds of low stiffness could not, by themselves, exert sufficient contact separating force to interrupt a circuit carrying high power. In the switch of the

present invention, contact sticking from all causes is overcome by means of the contactor 12.

When a magnetic actuating field for the switch of this invention decays, separation of the reed tips somewhat increases the net resistance of the switch, so that there is some potential difference between the contacts 18. But the switch still remains effectively closed, owing to the engagement of the contactor with the reed 6'; and therefore the electrostatic attraction between the contacts 18 is negligible and does not interfere with their rapid separation.

As the reed 6 moves rearwardly towards its post 11, it acquires a high velocity, being accelerated by a combination of its own flexing force and that due to the contactor preload. By the time it re-engages the arm of the contactor it has a large momentum. In consequence, the reed 6 literally knocks the contactor out of engagement with the reed 6', overcoming any tendency for the contacts 13 and 23 to stick to one another. In thus providing for abrupt, forceful contact separation at switch opening, the contactor enables the reed switch of this invention to interrupt as high as 3,000 volts at .5 amp., with surge voltages at break that are as high as about 15,000 volts.

The current that a switch is required to break normally determines its service life expectancy. The switch of this invention has been found to have a substantially longer useful life than prior reed switches even when breaking currents of as high as 5 amperes. At 0.5 amperes d.c. a switch of this invention has been found to be still useable after more than 200 million operations; and with lower currents its useful life would increase in a nearly linear inverse relationship to current.

This long service life is due to the particular

metals of which the contacts 13 and 23 are made. As noted above, the contact 13 is an integral part of the contactor 12, which is made of a single piece of molybdenum wire, and it cooperates with a tungsten contact 23 on the reed 6'.

If the contacts 13 and 23 were both of tungsten, operating in a deep vacuum, they would open without sparking or arcing, but a certain amount of tungsten would transfer from the positive contact to the negative one at each switch opening. This transfer of material to the negative contact is the well known low voltage phenomenon that occurs in arcless, sparkless separation of any switch contacts through which current is flowing. The reason for it is fairly well established. When a pair of contacts begins to make an arcless separation, their resistance increases rapidly as the contact force diminishes. Just as contact pressure goes to zero, the contacts are engaging each other at an infinitesimal point through which all of the current in the circuit must flow, and the energy thus charged into the contact metal in this very localized area heats it above its melting point, however high this may be. The molten particle of metal thus formed is for a brief instant held in place by surface tension, bridging the separating contacts, but as the contacts continue to move apart its surface tension collapses and it settles back onto the contacts. However, most of the molten metal settles onto the negative contact, because the positive contact becomes hotter than the negative one. While the amount of metal thus transferred at each opening is relatively small, it varies in more or less direct proportion to the amount of current carried by the switch.

When the switch of this invention is connected in a d.c. circuit, or in any circuit in which current is always expected to flow in the same direction at the instant of switch opening, it

should be so connected that its terminal 9 will be the positive one at the instant of switch opening and its terminal 9' will be the negative one. This is to say that the molybdenum contact 13 will be positive and the tungsten contact 23 will be negative.

Hence when the contacts begin to separate, molybdenum from the contact 13 will be transferred to the tungsten contact 23 in accordance with the usual phenomenon of low voltage material transfer. As the contacts continue to move apart, the bridge of molten molybdenum across the two contacts reaches its collapsing point, and a voltage difference appears between the contacts. Under the influence of this voltage difference an abundance of electrons is emitted by the molten molybdenum on the negative contact, producing a more intensified local heating there which causes ionized molybdenum to be emitted into the space between the contacts.

Apparently a full plasma arc does not develop between the contacts, but there appears to be an incipient arc in the nature of a cathode spot on that part of the contact 23 to which molybdenum has been transferred. From that cathode spot most of the molybdenum ions are emitted, and such ions tend to move toward the anode, i.e., the contact 13 from which they originated and from which they were transferred as molten molybdenum. Because of the deep vacuum environment of the contacts, they do not oxidize, and therefore the vaporized molybdenum which is redeposited on the molybdenum contact 13 readily adheres thereto.

Thus the arcless transfer of molten molybdenum from the contact 13 to the contact 23 that occurs in the initial phase of contact separation is in large measure offset or compensated for by the retransfer of molybdenum back to its original site, occuring by reason of the ionization that takes place in the immediately succeeding phase of contact separation.

The tungsten does not take part in the transfer and retransfer described above, because its melting and vaporizing temperatures are substantially higher than those of molybdenum and because in the very first phase of contact separation, when arcless transfer is occurring, the tungsten contact is the one to which such material transfer always takes place, so that molten molybdenum is being deposited onto it. At the power levels for which the switch of this invention is intended the temperature of the cathode spot is determined by the characteristics of molybdenum; or in other words there is not enough power to support ionization of the tungsten once the molybdenum is vaporized off of it.

The foregoing explanation for the long service life of the switch of this invention in d.c. applications may not be complete, and may be inaccurate in some respects, but it is consistent with the results that have been obtained with the switch of this invention and also with known phenomena of switch contact behavior and the generally accepted theories for them.

The explanation tends to be confirmed by what happens when the switch of this invention is wrongly connected in a d.c. circuit, with its terminal 9 negative and its terminal 9' positive. Under those conditions the negative molybdenum contact 13 is sufficiently cooler than the positive one so that an accumulation of tungsten develops on it, and the switch has a substantially shorter useful life than when properly connected, failing when the tungsten contact becomes pitted or eroded to the point where the substrate metal is exposed and the contacts stick because of welding or mechanical friction. Retransfer of the tungsten cannot occur under these conditions because of the extremely high vaporizing temperature of tungsten, which prevents the occurrence of an effective cathode spot at power levels within the capabilities of the switch.

Further confirmation of the correctness of the above explanation appears from the fact that the switch of this invention actually has a somewhat shorter life in a low voltage, low inductance circuit, even when correctly connected, than in the higher power circuits for which it is intended. Thus when a switch of this invention was installed in a substantially non-inductive circuit carrying 2 amperes at 1-1/2 volts, molybdenum was found to transfer rather steadily from the positive contact 13 to the negative tungsten contact 23, with no evidence of retransfer. It should be pointed out that a circuit of this type (which would usually be in the nature of a heater circuit) is one in which a reed switch would not be likely to have particular value, and that even under these comparatively adverse conditions the useful life of the switch of the present invention was several times that of the best prior reed switches.

It will be seen from the foregoing explanation that the long useful life of the switch of this invention is due to the spread or difference between the melting and vaporizing temperatures of the two metals comprising the respective contacts 13 and 23 and the deep vacuum environment in which they operate. Contacts of other materials could be used in a switch embodying the principles of this invention provided that the material of the negative contact was one that did not produce an effective cathode spot within the power levels for which the switch was intended, and that the material of the positive contact did so; and provided, of course, that such contacts were in a deep vacuum. However, tungsten and molybdenum are the preferred metals because both of them melt at high enough temperatures to obviate the possibility of the contacts being welded shut, and both are hard enough to resist mechanical wear that might in time produce frictional sticking.

While the tungsten/molybdenum contact pair of the switch of this invention undoubtedly has a higher resistance than contacts of the softer metals, other factors pointed out hereinabove compensate for this to provide the switch of this invention with a relatively low net resistance.

Of course the switch of this invention will not last forever. A certain amount of the molybdenum that is vaporized at each switch opening is dissipated to the wall of the envelope 7, and not all of the molybdenum that is transferred to the tungsten contact 23 will be re-engaged by the contactor 12. Obviously the molybdenum that is deposited in locations where it is never again contacted by the molybdenum contact cannot take part in cathode spot vaporization and therefore cannot be transferred back to the molybdenum contact member. Hence after some hundreds of millions of operations in a high power d.c. circuit, the molybdenum contactor will fail because of such dissipation of the material of its contact portion. But with these considerations in mind, it is possible to prolong the life of the switch by providing the contactor with a contact surface of substantial area, to afford the greatest possible opportunity for transfer back to it of molybdenum deposited on the tungsten contact 23. To this end the wire of the bight portion of the contactor is preferably flattened as shown in Figure 6.

Besides affording long service life as explained above, molybdenum wire makes a good contactor because it is ductile enough to be readily formed to the desired shape and has sufficient resiliency to provide the desired biasing force. A further advantage of molybdenum wire is that it continues to support bending stresses at temperatures as high as 1400° F. and above. This means that the contactor 12 can be bonded to the reed 6 before that reed

is heated to outgas it and fix its preload against its post 11. Of course the contactor should be fastened to the reed 6 with a preload substantially higher than that which it is intended to have in the finished switch, since a certain amount of stress relieving of the contactor will occur as it is heated during outgassing of the reed assembly. However, if contactors are always assembled under an initial preload which is equal to the yield point of the material, and the reed assemblies are always heated to a particular maximum degassing temperature such as 1500° F., the preload of the contactor against the reed 6 will always have a value, in the completed switch, that is directly related to the temperature to which it was heated.

From the foregoing description taken with the accompanying drawings it will be apparent that this invention provides a magnetically operated reed switch that is capable of closing and opening in very fast and faithful response to the rapid buildup and decay of a magnetic actuating field; and that the switch of this invention is capable of controlling substantially high volt-ampere circuits in rapid cycling, with an extremely long service life even in d.c. applications.

The embodiment of the invention in which an exclusive property or privilege is claimed is defined as follows:

1. A switch comprising a pair of contacts at least one of which is movable toward and from engagement with the other, for repeatedly opening and closing a circuit in which an electric current always flows in the same direction at the time of separation of said contacts so that at such times a first one of said contacts is always connected with the negative terminal of the source of current for the circuit and the other with its positive terminal, said switch being characterized by: means defining an evacuated hermetically sealed enclosure enclosing the contacts by which they are maintained in a deep vacuum environment; said first contact being of metal having melting and vaporizing temperatures at least about as high as those of tungsten; and said other contact being of a metal having lower melting and vaporizing temperatures than the metal of the first.

2. The switch of claim 1, further characterized by: said other contact being of molybdenum.

FIG.1.

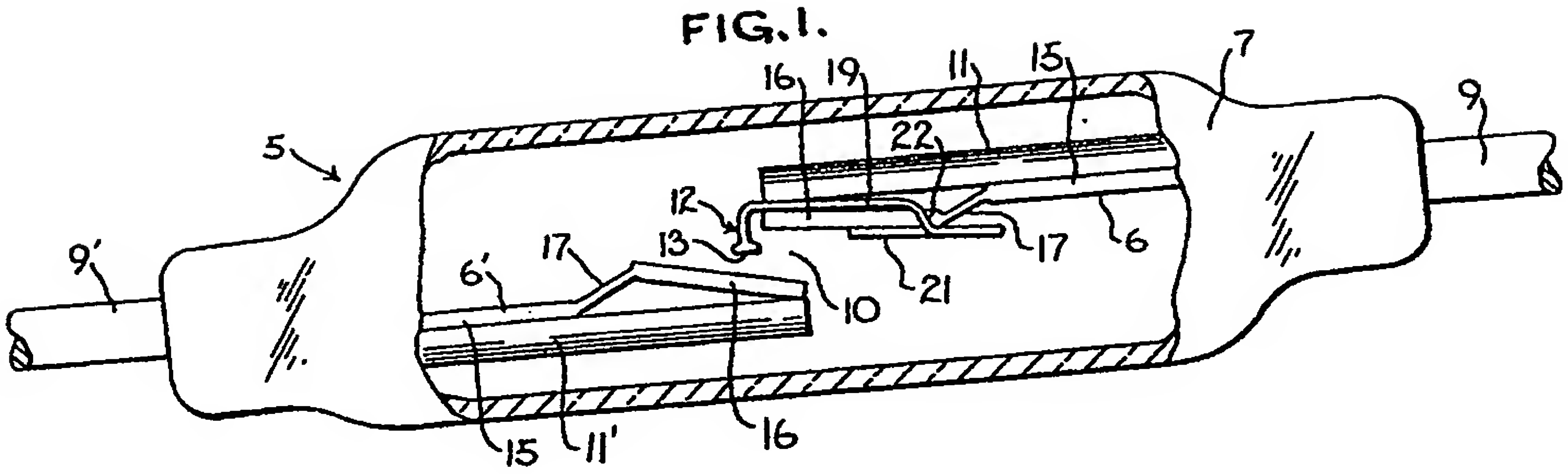


FIG.2.

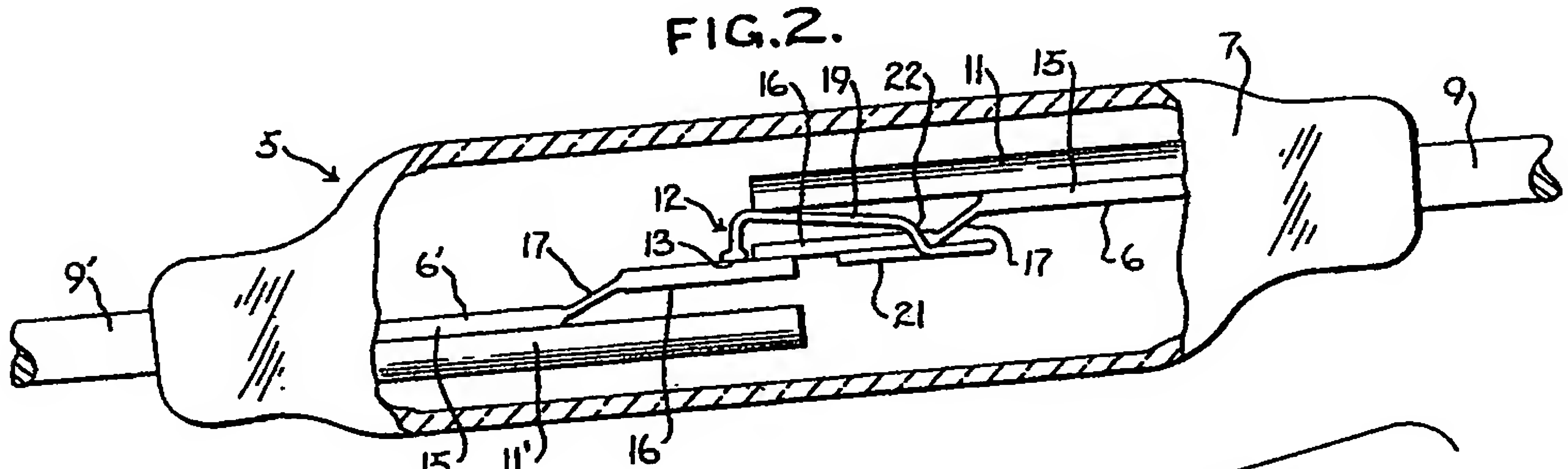


FIG.3.

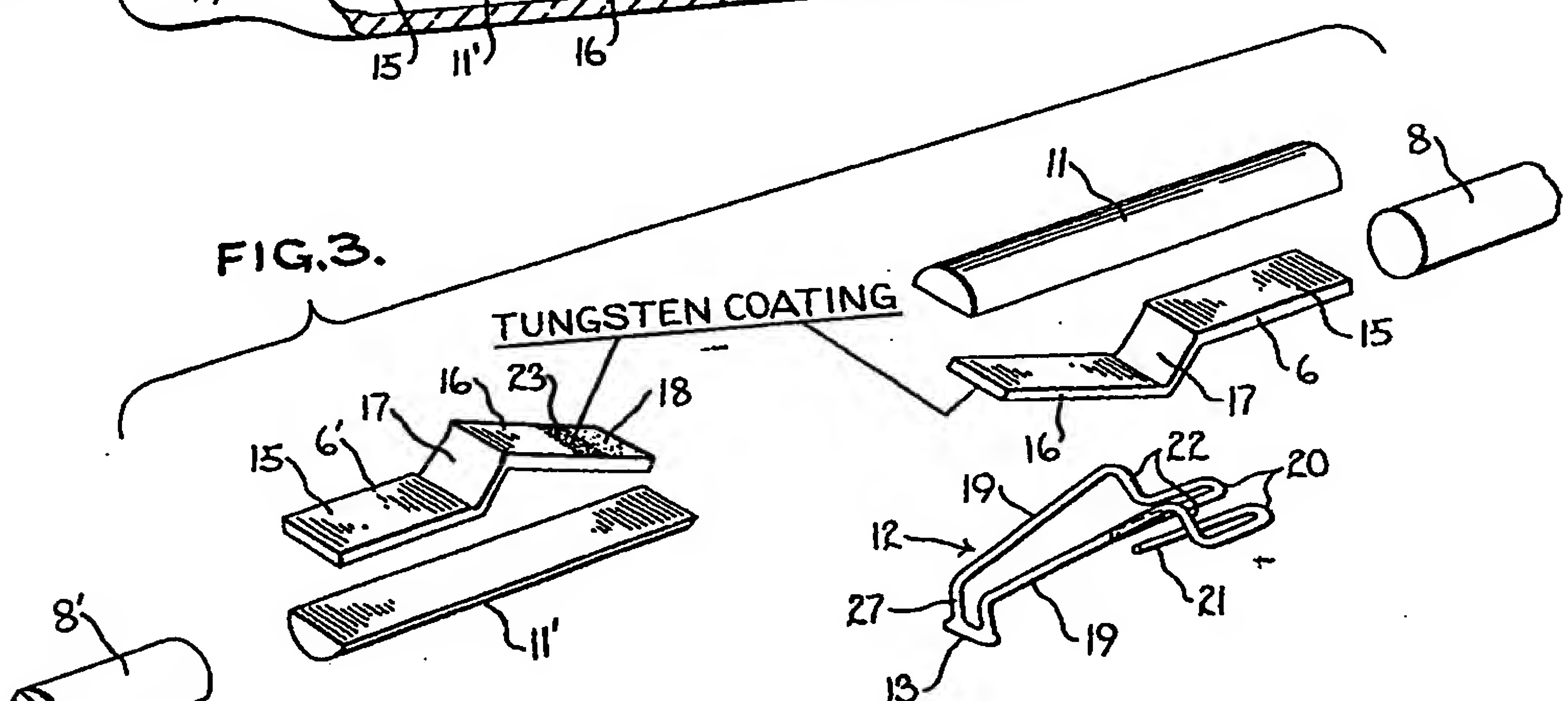
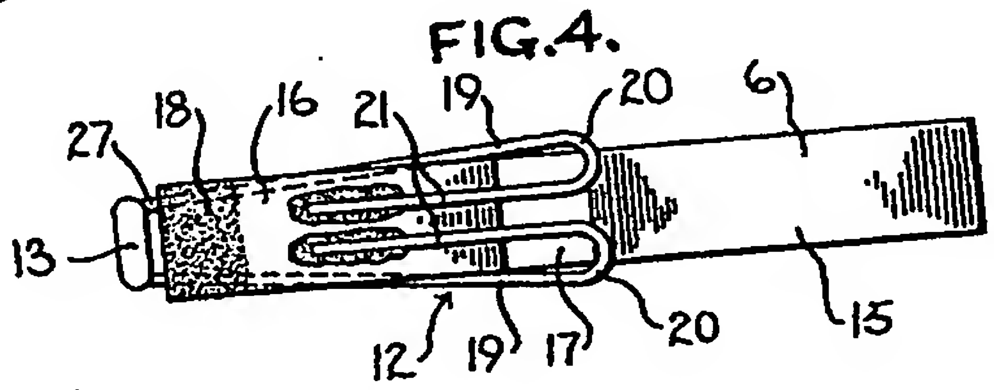


FIG.4.



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